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The mobile communication antenna structures classification

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The article analyses the problem of mobile communication antenna structures classification, considers their main design features, advantages and disadvantages. Generalized classification of mobile communication antenna structures operated in Ukraine is proposed. The regular recurrence of accidents and destruction of antenna structures indicate that the existing methods of calculation and design of such structures do not always take into account all their structural features. Technical and constructive solutions, peculiarities of operation of structures under load, aspects of application and their requirements for safe operation are considered, strengths and weaknesses of each type of antenna structures are given. One of the most effective and widely used antenna structures are lattice towers and masts. The main advantage of lattice towers is a small building area, however, from the point of view of consumption, steel masts are more cost-effective with the same height of the structure and payload. However, the cost of building an antenna structure is not always the main criterion for choosing its design scheme. First of all, radio-technical, technological and architectural requirements are of great importance. In the absence of restrictions on geometric parameters, preference is given to towers with a minimum number of faces, for example, when going from a 3-faceted to a 4-faceted tower, its weight increases by 10%. For technical and economic efficiency, not only rational types of cross-sections of elements are selected, but also various combined structural systems are developed. A good example is introduction into mass construction of combined supports on the basis of a conical concrete monopole CK-26, on top of which a steel lattice extension is installed. The structural disadvantage of the combined supports based on the conical concrete monopole CK-26 is their limited bearing capacity at the +2,000...+3,000 m mark, which in a number of cases led to accidental destruction in this particular area.

Key words: antenna structures, classification, mast, tower, combined support.

Класифікація антенних споруд мобільного зв’язку

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У статті проаналізовано класифікації антенних споруд мобільного зв’язку за конструктивною схемою, розміщенням, матеріалом, типом перерізу та просторовою формою стовбуру; розглянуто їх основні особливості, переваги та недоліки. Узагальнена класифікація антенних споруд складена для тих, що експлуатуються на території України. Регулярна повторюваність аварій та руйнувань антенних споруд вказує на те, що існуючі методи розрахунку і проектування таких конструкцій не завжди враховують їх усі конструктивні особливості. Розглянуто технічні та конструктивні рішення, особливості роботи споруд під навантаженням, аспекти застосування та їх вимоги до безпечної експлуатації. Одними з найбільш ефективних та масово використовуваних антенних споруд є решітчасті вежі та щогли. Основною перевагою решітчастих веж є невелика площа забудови, однак з точки зору витрати сталі щогли є більш економічно ефективними при однаковій висоті споруди та корисному навантаженні. Проте, вартість будівництва антенної споруди не завжди є основним критерієм вибору її конструктивної схеми. Передусім, велике значення мають радіотехнічні, технологічні й архітектурні вимоги. При відсутності обмежень на геометричні параметри перевагу віддають вежам з мінімальною кількістю граней, наприклад, при переході від 3-х до 4-х гранної вежі її вага збільшується на 10%. Для техніко-економічної ефективності не тільки підбираються раціональні типи поперечних перерізів елементів, а й розробляються різні комбіновані конструктивні системи. Яскравим прикладом є впровадження у масове будівництво комбінованих опор на базі конічної залізобетонної стійки СК-26, поверх якої встановлена сталева решітчаста надставка. Конструктивним недоліком комбінованих опор на базі конічної залізобетонної стійки СК-26 є їх обмежена несуча здатність на відмітці +2,000…+3,000 м, що в ряді випадків призводило до аварійних руйнувань саме на цій характерній ділянці.

Ключові слова: антенні споруди, класифікація, щогла, вежа, комбінована опора.

Introduction

At the beginning of the development of mobile communication in Ukraine, one of the main disadvantages was a drastic deterioration in the quality of communication due to insufficient coverage or the remoteness of the user from the base station. The solution to this problem was the rapid and massive expansion and densification of the network of base stations and the modernization of already existing antenna-feeder equipment at antenna facilities. This greatly contributed to bringing the quality and speed indicators of telecommunications to a qualitatively new level [1]. However, the fast, massive, sometimes chaotic and unregulated construction had negative consequences, which was primarily reflected in the reliability of antenna structures, the inefficiency of the adopted constructive decisions and non-compliance with the requirements of the current legislation [2]. Today, the use of modern computers and software complexes in static and dynamic calculations, analysis of the reliability of antenna structures allows solving complex problems with a high degree of static uncertainty [3; 4]. In the past, it was practically impossible to solve problems of this complexity, and we had to be satisfied with approximate results.

Review of the research sources and publications

A number of foreign and national scientists were engaged in the research of mobile communication antenna structures. Currently, researchers have proposed a number of classifications of antenna structures, many features of each type have been considered. Molchanov raises the problem of the emergency of mobile communication facilities. The author notes a number of the main causes of accidents and recommendations for their prevention [5]. In their publication, Holodonov and Doan investigate the main impacts on antenna-mast structures during their operation, proposing a methodology for determining a complex risk indicator [6]. Nielsen in his work raises the problem of effective selection of types of structures in accordance with operating conditions, principles of their operation, specifics of perception of wind and ice loads [7; 8].

Definition of unresolved aspects of the problem

The regular frequency of accidents and destruction of antenna structures [9] indicates that the existing methods of calculation and design of such structures do not always take into account all their design features [10-12]. In addition, the study of the condition of antenna structures, their classification will allow to solve a large number of problems related to the general characteristics of the existing fund and predict problems that may arise in the future [13-14]. Available information and research in the field of antenna structures of mobile communication requires a clear classification, structuring and generalization.

Problem statement

The purpose of this work is the analysis and classification of antenna structures according to their structural features and the systematization of information about them.

Basic material and results

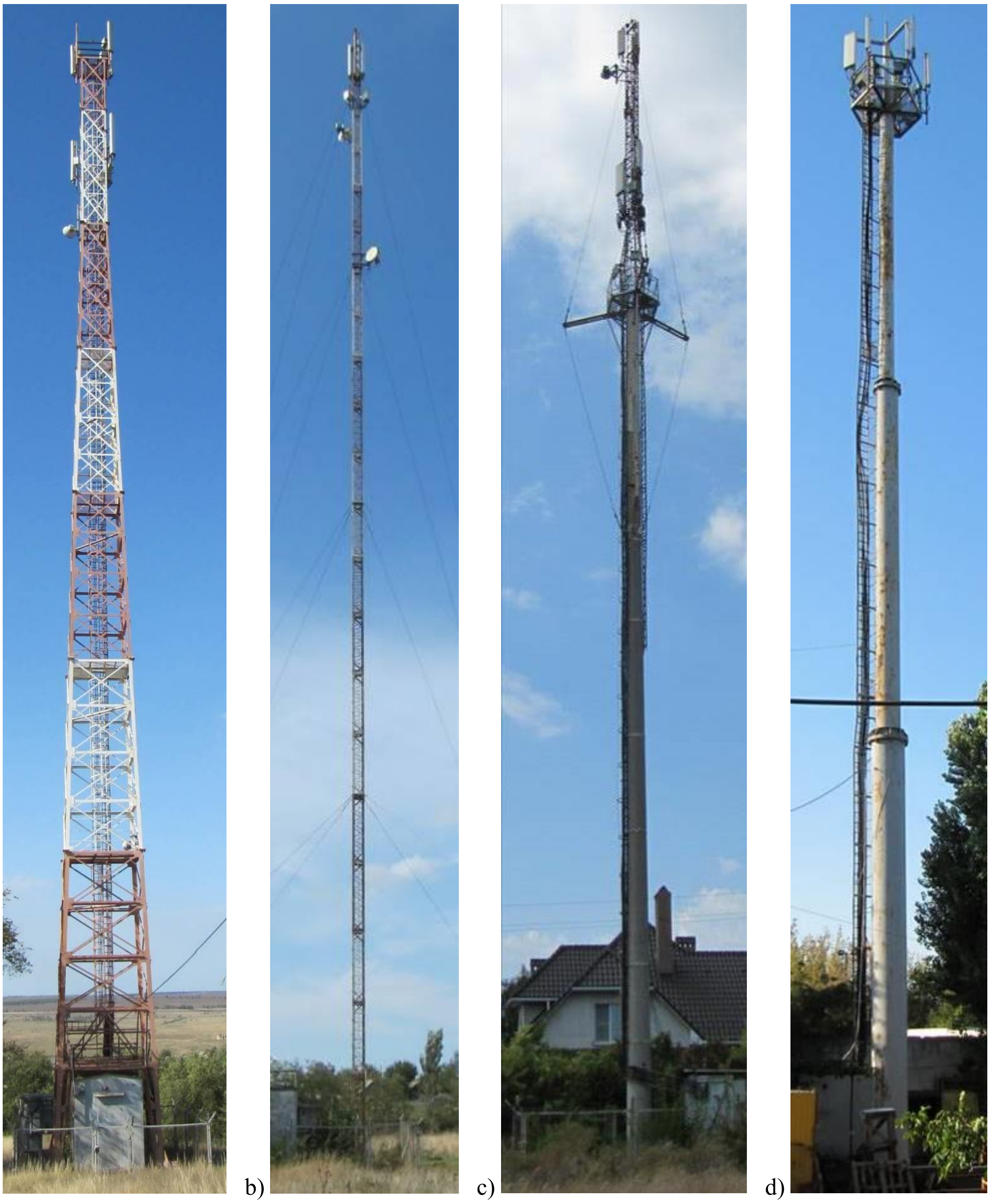
Antenna structures are a wide class of structures that are designed for placing technological and radio equipment on them. According to the construction scheme, antenna structures are divided into towers, masts and combined supports (see Fig. 1) [15]. A distinctive feature of antenna structures is their high height compared to the dimensions of their cross-sections, so their designs are mainly designed for atmospheric loads (wind, ice, temperature) [16-17].

To a large extent, the technical condition of antenna structures depends on the features and stages of communication development in Ukraine. The process of determining the technical condition of an individual construction is greatly simplified when data on design features, operation, durability and reliability of similar buildings are known.

Based on the own statistics of the results of technical surveys for the period 2017-2023, among the total number of 1,600 mobile communication antenna structures, masts make up – 41%, towers – 27%, combined supports – 9%, tubular towers – 3%, masts and large pipe supports on the roof – 20% of the total number of network objects. Depending on the specifics of the region and the density of buildings, the ratios for the types of structures may differ slightly.

The placement of mobile communication antenna structures is primarily conditioned by urban planning restrictions, the existing high-rise buildings and the possibility of potential lease of the land plot. Based on the characteristics of the area and the request of radio planning engineers regarding the need to expand the network, a decision is made on the feasibility of using a certain type of structures. Antenna structures can be placed on their own free-standing foundations, on the roofs of buildings, on other high-rise structures (smokestacks, water towers, etc.), on a technological container with the help of a support frame. In the absence of land lease restrictions, in rural areas constructions on their own foundations are usually preferred. This makes it possible not to be limited in the choice of the structural scheme of the building and to adopt the most economically attractive option.

In conditions of high-rise urban buildings, it is more appropriate to use the existing height effectively to place antenna structures on the roofs of buildings, while minimizing the required height of antenna structures and solving the potential problem of radio shading of adjacent buildings (reduction of signal quality due to the density of buildings). In addition, in a dense urban development, it is sometimes extremely difficult to find a potential site for the construction of buildings on their own foundations, and if it is available, it may be economically impractical for construction. Placement on other high-rise structures (smokestacks, water towers) is rational in industrial buildings, using the existing structures to install the necessary equipment with practically no additional requirements for the maximum wind area or weight.



a) b) c) d)

Figure 1 – General view of the tower (a), mast (b), combined support (c) and tubular tower (d)

Design schemes. Antenna structures are divided into towers, masts, combined supports, pipe supports on buildings and smokestacks.

A mast (see Fig. 1b) is a rigidly or hinged support installed on the foundation, which is unfastened in height by a system of elastic supports – braces – placed in one or more tiers. The cross-section of the trunk of the masts is most often lattice triangular or square, in some cases solid round. In the plan, the braces are placed in three or four directions. The number of tiers in height is from one to seven tiers. The optimal angle of inclination of the braces is 45-60°, with a further increase in the angle of inclination of the braces, the forces in the belts of the mast trunk increase. For each direction of braces, one foundation can be installed for all tiers, and separate foundations for each tier of braces.

The calculation scheme of the mast is a continuous multi-span beam, in which the elastic supports are the connecting nodes of the braces. Ties are flexible threads that are loaded with their own weight, the weight of ice and the force of the wind, the ends of which are fixed at different levels and have a preliminary tension. Such a cable-rod system has a complex operation under load and pre-tension of the ropes, which is related to the operation of the tensioners as flexible threads, and the calculation scheme may change when the load changes. Calculations of such a system are performed according to the deformed scheme by methods of gradual approximation.

The reliability of antenna-mast structures primarily depends on the technical condition of the ties, which are made of steel ropes. The situation is complicated by the widespread use of ropes with an organic (hemp, sisal) or synthetic (polypropylene) core as tensioners, which have increased flexibility and are intended for use in pulleys, winches, elevators and are not intended for use in tensioners of antenna-mast structures, have significantly less (by 20-30%) breaking force in contrast to ropes with a steel core.

In the basic scenario, masts are more economical than towers, but a much larger area is required for their installation (for masts, the building area can be approximately 400-800 m^2, for towers of a similar height – 20-40 m^2). In addition, masts can perceive the useful antenna load much less than lattice towers.

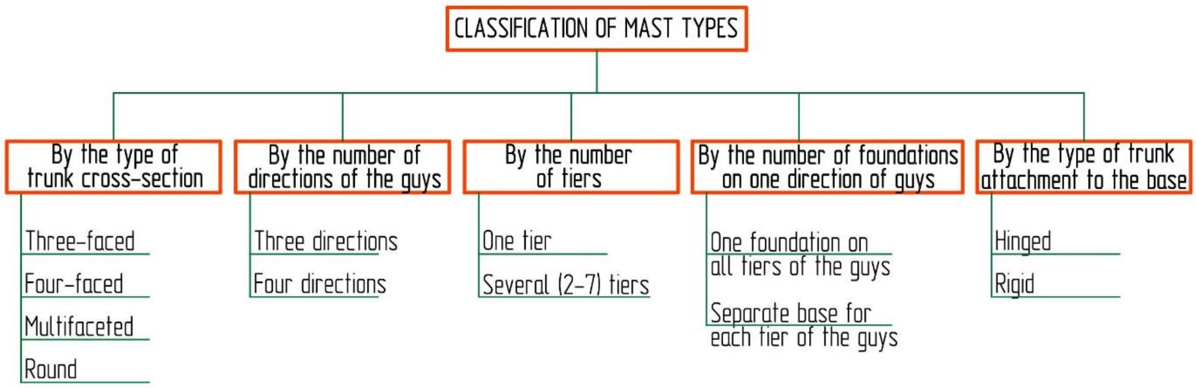


Figure 2 – Classification of mast types

Tower (see Fig. 1a) is a cantilever-type support rigidly installed on the foundation. According to the type of cross section, the towers are divided into through (lattice) and continuous (tubular, conical) towers.

According to their design features, the towers belong to complex engineering structures, this is due to their functional purpose and the nature of the force loads they perceive during operation. The use of towers has an advantage for construction in mountainous conditions when it is difficult to place anchor foundations for mast braces.

The most widespread is the design of the tower, the geometric scheme of which fits into the figure formed by the rotation of a broken line around a vertical axis. Due to belt breaks, the shape of the tower approaches the one that follows the shear of moments from wind load.

Lattice towers usually have a triangular or square, rarely polygonal cross-section. The tower consists of pyramidal or prismatic sections with combined bases. The main elements of the tower are belts, the axes of which coincide with the edges of the sections, struts and braces are placed in the plane of the faces. Rigid diaphragms are installed in part of the cross-sections (at a distance of no more than 3 cross-sections), which prevent the cross-section from changing.

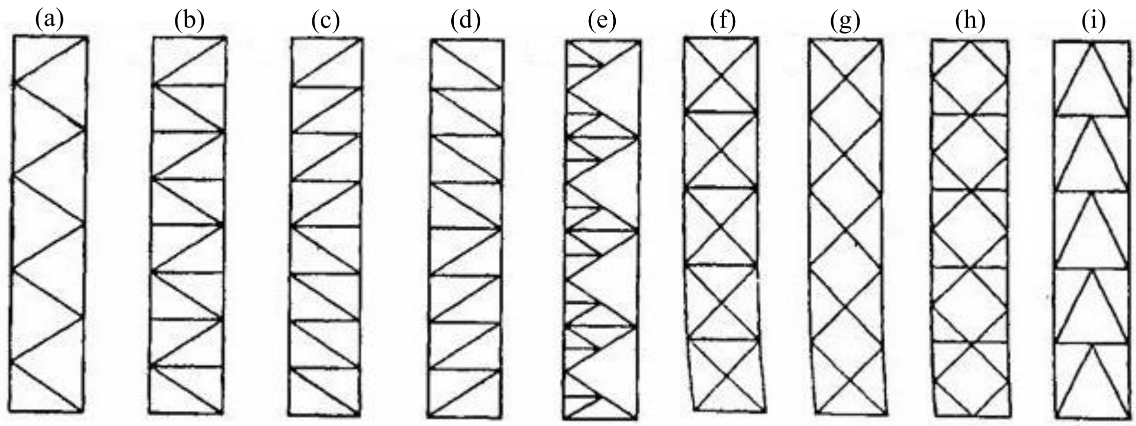


Figure 3 – Types of tower lattices: triangular (a), triangular with additional supports (b), canted with ascending braces (c), canted with descending braces (d), sprengel (e), cross (f), crosswise (g), rhombic (h), semi-canted (i)

Canted and triangular lattices (see Fig. 3a-d) consist of elements that work both in compression and tension. The cross-sectional area of the elements is selected according to the compressive strength. These grids have a relatively smaller number of elements and simple connection nodes. They are convenient for manufacturing and installation, but braced and triangular lattices are used for small panel sizes (relative to the cross-section of the element) in order to avoid increasing the weight of braces and spacers due to limitations in their flexibility.

Cross lattice (see Fig. 3f) in towers usually it is used with braces, which are excluded from work in compression and work only in tension. At the same time, only compressive force occurs in the spacer, which connects the intersection nodes of the braces with the belts. An auxiliary spacer in the grid serves to unfasten the free length of the belt. The structure of the cross lattice allows pre-tensioning of its elements (braces made of round steel with tension couplings). Compared to the diagonal and triangular lattice, it has more complex nodes.

In the rhombic lattice (see Fig. 3h) the main struts are absent, and the braces work in compression and tension. As in the cross lattice, the additional strut serves to untie the free length of the belt.

Cross and rhombic lattices are most often used in the construction of mobile communication towers. They are very different from each other by the nature of work. Under equal conditions (the same magnitude of the transverse force, the size of the panels, the type of cross-section of the belt elements), the cross-sectional area in the braces of the rhombic lattice is selected for the force approximately two times less than in the braces of the cross. This circumstance often puts the rhombic lattice in a more favourable position compared to the cross lattice.

Semi-canted grid (see Fig. 3i) is used much less often, mainly in those cases when it is planned to place a large number of antenna-feeder equipment on technological sites and with increased requirements for the deformability of the tower. It is distinguished by the relative simplicity of nodes compared to other types of lattices, but under normal conditions it has a greater relative weight than the cross lattice.

In the absence of restrictions on geometric parameters, preference is given to towers with a minimum number of faces. The weight of the tower depends on the number of faces. For example, when moving from a 3-faced tower to a 4-faced tower, its weight increases by 10%, and the difference in the number of main elements can be up to 35%.

The height of lattice towers varies in a wide range - from 40 to 500 m. Lattice towers are usually made of corners or tubular elements. The belts of the tower rest on free-standing reinforced concrete foundations that act in compression, pull-out force and shear force.

Tower structures are more convenient for installation and operation of antenna-feeder equipment, as well as for maintenance of the structure itself, since there is no need for periodic adjustment of tension and replacement of ropes, unlike in masts.

Tubular tower (see Fig. 1d) is a cantilever support of a solid cross-section, consisting usually of several separate tubular sections 6-12 m high, the sections are connected on the flanges with the help of high-strength bolts. The height of tubular towers is most often in the range of 30–50 m. The construction of tubular towers of greater height is not implemented, because the design solution completely loses its economic feasibility. The main advantage of this type of construction is the minimum requirements for the building area and relative invisibility in the architectural ensemble of the city, however, the cost of construction is much higher than other structures of similar height.

Combined support (combination of tower and mast, see Fig. 1c) is a conical concrete monopole CK-26 rigidly buried in the ground, on top of which a lattice extension is installed, unfastened by additional elastic supports - braces, which are attached to horizontal elements (beams).

The appearance of combined supports is due to unification of structures with an economically acceptable price and with minimal requirements for land acquisition of the site for development. This type of construction generally met the above requirements and played a significant role in the rapid deployment of the cellular network throughout Ukraine. But it also had its design flaws, namely the limited bearing capacity of the conical concrete monopole CK-26, which in turn imposed rather strong restrictions on operation in various windy areas and the installation of the maximum possible number of antenna-feeder equipment. As a result, during operation with an increase in the number of antenna-feeder equipment on the antenna structure, the maximum moment in the rack may exceed the permissible moment in terms of bearing capacity. The failure of a reinforced concrete column occurs in a specific area at +2,000...+3,000m above ground level – a combination of close to the maximum moment and a decrease in the number of rods of prestressed reinforcement in the cross section of the column.

Types of connections. In the vast majority of cases, antenna structures are made prefabricated, in the form of starting marks – sections, 2-6 m high (for convenience of installation and transportation). Bolted connections are made through flanges or overlays made of rolled metal, usually using bolts of strength class not lower than 8.8 (see Fig. 4). Less often, sections are connected using welding or bushings (boltless, exclusively in masts).

The calculation of bolted connections, depending on their type, is performed both for tensile forces (flange connections) and shear forces (connections on pads). When determining the number of bolts in flange connections, they tend to reduce their diameter. This leads to a decrease in the diameter of the circle along the centers of the bolts and, as a result, to a decrease in the weight of the flanges. The calculation of the thickness of the flanges is performed taking into account the work of the pipe wall.

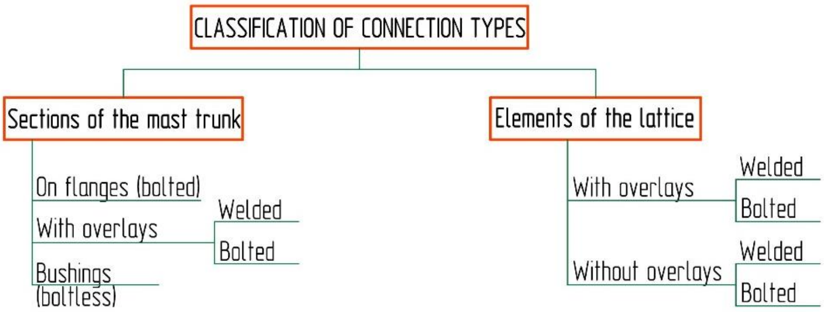


Figure 4 – Classification of connection types in antenna structures

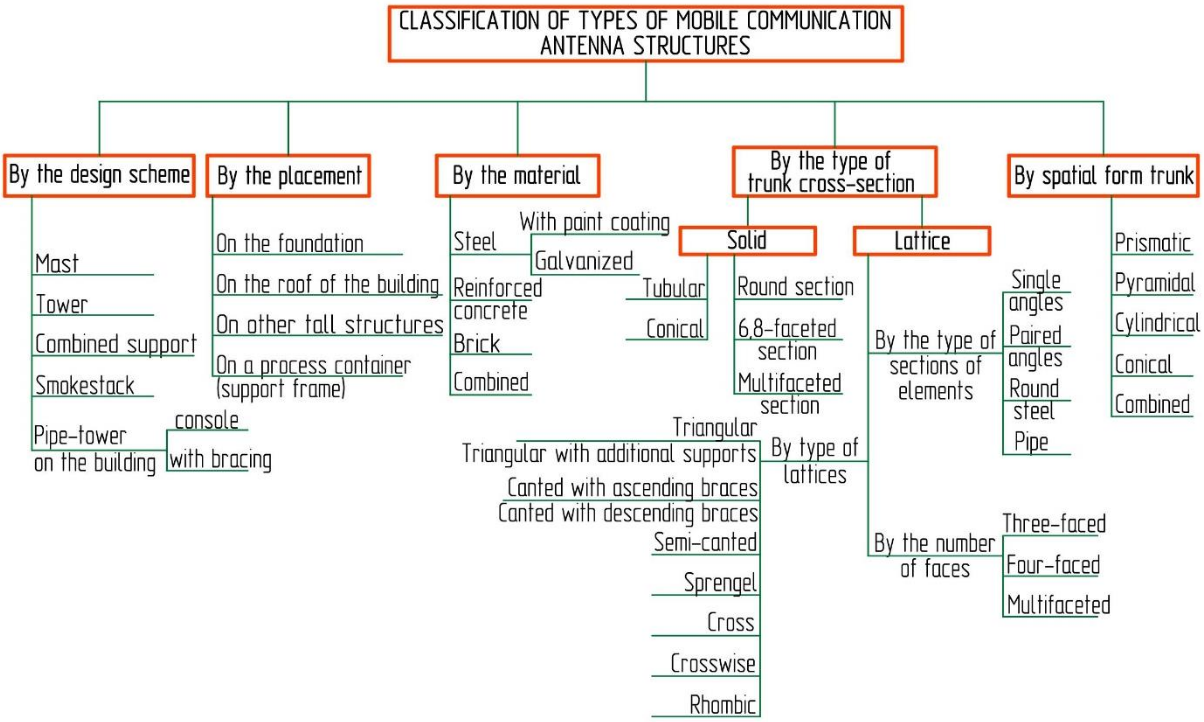


Figure 5 – Classification of types of mobile communication antenna structures

Conclusions

In the article a generalized classification of types of mobile communication antenna structures that are operated on the territory of Ukraine is provided (see Fig. 5).

The cost of building an antenna structure is not always the main criterion for choosing its design scheme. First of all, radio-technical, technological and architectural requirements are of great importance. In general, masts are more economical than lattice towers, but their installation requires a much larger area of land. In addition, masts perceive the useful antenna load less than lattice towers.

The use of lattice towers has an advantage for construction in mountainous conditions when it is difficult to place anchor foundations for mast braces. In the construction of lattice towers, cross and rhombic lattices are most often used. Under equal conditions (the same magnitude of the transverse force, the size of the panels, the type of cross-section of the belt elements), the cross-sectional area in the braces of the rhombic lattice is selected for the force approximately two times less than in the braces of the cross. This circumstance often puts the rhombic lattice in a more favourable position compared to the cross lattice.

In the absence of restrictions on geometric parameters, preference is given to towers with a minimum number of faces. The main advantage of tubular towers is the minimum requirements for the building area and relative invisibility in the architectural ensemble of the city, however, the cost of construction is much higher than other structures of similar height. When moving from a 3-faced to a 4-faced tower, its weight increases by 10%, and the difference in the number of elements can be up to 35%.

The appearance of combined supports solved the demand for fast and massive construction, for the unification of structures and for minimum requirements for the building area. But it also has its design flaws, namely the limited load-bearing capacity of the conical concrete monopole CK-26, which in a number of cases led to accidental destruction.

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